JOURNAL OF MARITIME RESEARCH

SPECIAL ISSUE (2026) pp 179–183

ISSN: 1697-4840, www.jmr.unican.es

Geodesy and Global Navigation Satellite Systems for Mean Sea Level Height Determination in Oman

Amol Ganesh Deshmukh[1,*], Khalifa Juma Al-Fazari[2]

ARTICLE INFO

Special Issue:
1st International Maritime and Logistics Conference;
February 10-11, 2026.
National University of Science & Technology (NU), Oman

Article history:
Received 15 Feb 2026;
in revised from 24 Feb 2026;
accepted 05 Jun 2026.

Keywords:
Geodesy, GNSS, MSL, Surveying, Geoid, CORS.

ABSTRACT

This paper presents the estimation of Mean Sea Level (MSL) heights across Oman using Geodesy and Global Navigation Satellite Systems (GNSS) techniques. Static GNSS data were collected using a Leica Viva Geosensor GS14 receiver with a CS15 Field Controller. The receiver was connected to the Oman Continuously Operating Reference Station (CORS) Network, under the control of the National Survey and Geospatial Information Authority (NSGIA) and provided centimeter-level positioning accuracy. The CORS network uses Global Positioning System (GPS) from the USA and Global'naya Navigatsionnaya Sputnikovaya Sistema (GLONASS) satellite signals from Russia to establish coordinate solutions based on the Oman National Geodetic Datum 2017 (ONGD17) geodetic datum. Oman Geoid Model was used get the geoid separation (N) which is then used to convert the ellipsoidal heights obtained from GNSS to the orthometric heights for ten surveyed points. These values are then compared to MSL heights provided by NSGIA. The smallest difference was found to be 0.028cm, largest 7.40cm with an average difference of 2.05 cm and a standard deviation of 2.17cm. The results indicate that high-accuracy determination of MSL heights using GNSS techniques is technically achievable in Oman. This can be effectively accomplished by properly applying the highly accurate local geoid model developed by NSGIA to convert GNSS-derived ellipsoidal heights into reliable orthometric heights.

1. Introduction.

Application such as engineering designs, simulation of flood, hydrographic surveys, management of large infrastructures and topographic mapping of terrain requires accurate Mean Sea Level (MSL) heights determined through geodesy. Traditionally, MSL heights have been obtained through precise levelling. This method although is very accurate but labourious, time consuming and not suitable for inaccessible areas. These problems are solved by Global Navigation Satellite Systems (GNSS) which is a satellite-based positioning technology.GNSS offers faster and flexible data collection covering those areas also which can not be covered by levelling survey.[1]

GNSS provides heights with respect to a mathematical ellipsoid called World Geodetic System 1984 (WGS84), which are significantly inaccurate and therefore can not be used for engineering and mapping applications. Hence these heights need to be corrected using an accurate geoid model to obtain MSL heights. The geoid represents the Earth's equipotential gravity surface approximated to MSL. GNSS derived orthometric height accuracy therefore depends heavily on the quality of the regional geoid model [2].

National Survey and Geospatial Information Authority (NSGIA) which is the national mapping agency of Oman has established several geospatial infrastructures such as Oman National Geodetic Datum 2017 (ONGD17) datum and a nationwide network of 47 Continuously Operating Reference Stations (CORS). This network provides real time kinematic and post processing corrections to improve the accuracy of GNSS en-

[1]Lecturer, Geomatics Engineering Department, Military Technological College, Oman.
[2]Assistant Lecturer, Geomatics Engineering Department, Military Technological College, Oman.
[*]Corresponding author: Amol Ganesh Deshmukh. E-mail Address: amol.deshmukh@mtc.edu.om.

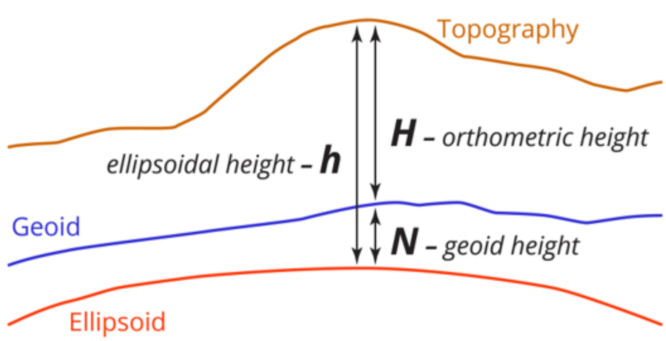
abled ellipsoidal height determination. Oman Geoid Model then allows the conversion of GNSS-derived ellipsoidal heights into orthometric heights consistent with the national vertical reference system.

Even with availability of these geospatial infrastructure, checking the reliability and estimation of accuracy of GNSS ellipsoidal heights in Oman remains important especially considering the varied topography of Oman. This research attempts to study the feasibility and assess accuracy of corrected GNSS heights from Oman Geoid Model.By comparing the resulting orthometric heights with precise spirit-levelled heights provided by NSGIA, the study offers capabilities, limitations, and potential improvements for GNSS-based height determination in the Sultanate of Oman.

2. Geodesy And Mean Sea Level (MSL) Heights.

The accuracy of GNSS height measurements largely depends on the representation of Earth's physical surface. In geodesy, the Earth's physical surface is considered close toan ellipsoid, which serves as the reference datum [3]. GNSS uses the WGS84 reference ellipsoid to determine ellipsoidal heights (h). However, these ellipsoidal heights do not represent true physical heights and therefore must be converted to MSL heights, referred to as orthometric heights (H) [4]. This conversion is achieved using a gravimetric geoid model, which provides the geoid height (N). As shown in Fig. 1, the geoid height represents the separation between the geoid and the ellipsoid.

Figure 1: Diagram showing relationship between h, H and N [5].



Source: Authors.

3. GNSS.

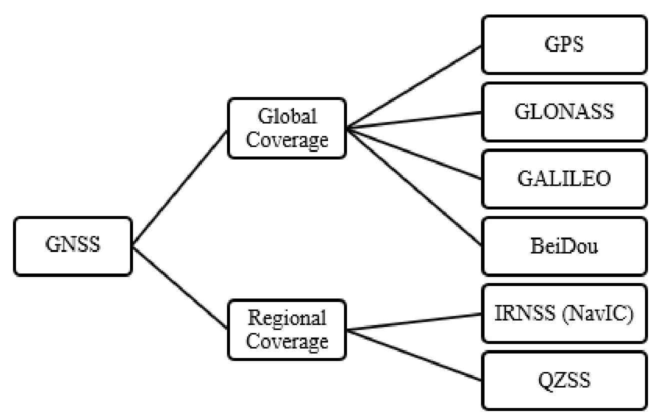
3.1. What is GNSS?.

GNSS is a space-based system that provide positioning, navigation, and timing services anywhere in the world. GNSS operates continuously, day and night, and is independent of weather conditions. It provides real-time data that is fairly accurate, economical, and significantly faster compared to traditional land-based surveying methods [6].

3.2. Global and Regional GNSS.

GNSS consist of both global and regional satellite constellations. Global GNSS systems offer worldwide coverage and operate continuously to support users anywhere on Earth. The main global constellations include the United States' GPS [13], Russia's GLONASS [14], the European Union's Galileo [15], and China's BeiDou or BDS or Compass [16]. These GNSS constellation send signals from medium Earth orbit satellites and form the backbone of modern navigation by delivering consistent and reliable global positioning, navigation and timing data. Unlike global GNSS, regional GNSS systems are created for specific countries with improved accuracy and signal availability. Indian Regional Navigation Satellite System (IRNSS) also called Navic and Quasi-Zenith Satellite System (QZSS) are the two regional GNSS existing so far., Both these regional GNSS improve performance within India and Japan respectively, by providing stronger, more precise signals. While global GNSS guarantees broad coverage, regional GNSS support them by offering improved accuracy and reliability where needed, especially in areas with challenging terrain or dense urban environments. [7] The global and regional GNSS classification is depicted in Fig. 2.

Figure 2: Global and Regional GNSS.

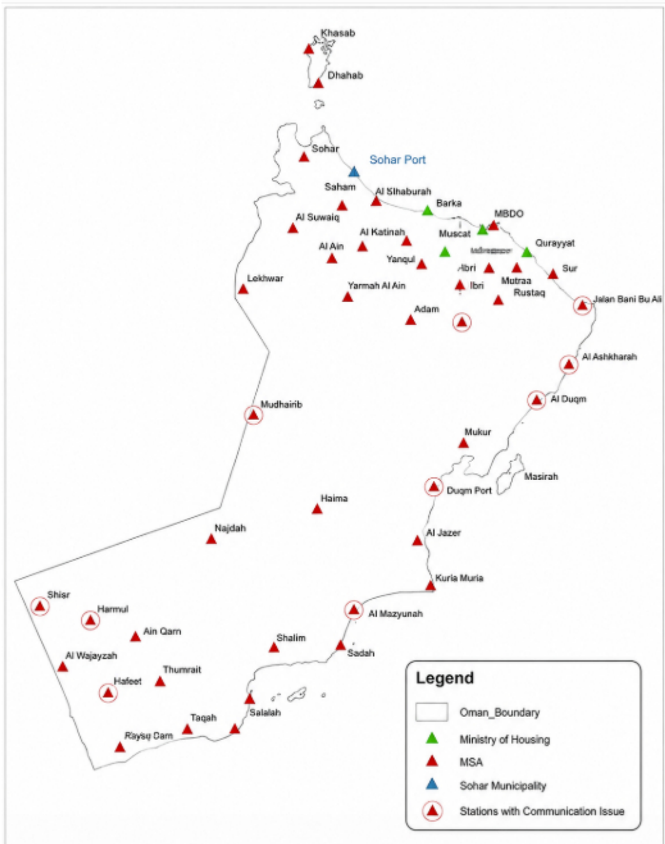


Source: Authors.

4. Oman Cors Network.

OmanCORSNet, created by NSGIA in 2016, uses the GPS and GLONASS satellite constellations and continuously records GNSS signals over 47 stations distributed throughout the country. Each of these stations are equipped with Leica AR10 antenna and GR25 GNSS receiver. This network provides real-time and post-processing positioning services to GNSS surveyors within the Sultanate of Oman. The system minimizes signal distortion and enhance positioning quality, enabling centimetre-level accuracy [8]. Fig. 3 shows the locations of all 47 CORS stations across Oman.

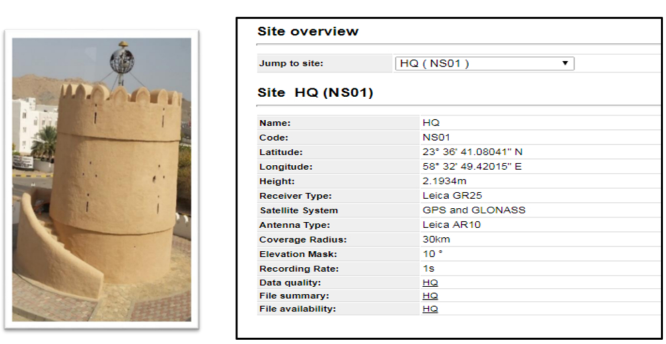
Figure 3: Map showing OMAN CORS network.



Source: Authors.

Considering the high cost of antenna and recievers, safe and secured places such as government offices are selected to install these stations which also ensures uninterrupted power supply and stable network connectivity. Details available for each station [9] are illustrated in Fig. 4.

Figure 4: Picture showing CORS Station at NSGIA with its details.


Site overview

Jump to site: HQ (NS01)

Site HQ (NS01)

Name:	HQ
Code:	NS01
Latitude:	23° 36' 41.08041" N
Longitude:	58° 32' 49.42015" E
Height:	2.1934m
Receiver Type:	Leica GR25
Satellite System	GPS and GLONASS
Antenna Type:	Leica AR10
Coverage Radius:	30km
Elevation Mask:	10 °
Recording Rate:	1s
Data quality:	HQ
File summary:	HQ
File availability:	HQ

Source: Authors.

5. Equipment Used And Survey Methodology.

To determine the most suitable date and time for data collection, GNSS planning was carried out before the start of the survey. GPS and GLONASS constellations were selected, and only healthy satellites were included from the constellation library. A cutoff angle of 15 degrees was chosen as it maintains an average visibility of 8–10 satellites throughout the survey period. The planning provides charts showing satellite elevation, the number of available satellites, Dilution of Precision (DOP) values, satellite visibility, and ionospheric conditions. The DOP values were found to be less than 2, confirming that the selected survey time was excellent for GNSS observations.

Figure 5: Leica GS14 and CS15 and the Field Survey set up.

Source: Authors.

For the field measurements, a Leica Viva GS14 Geosensor paired with a CS15 field controller was used as shown in Fig. 5. This equipment is a dual-frequency, survey-grade receiver capable of delivering centimetre-level accuracy [10]. The receiver was connected to the Oman CORS network via the internet to obtain Real-Time Kinematic (RTK) corrections, further improving accuracy. The Oman CORS network is designed to support height determination based on the ONGD17 datum. The static GNSS method was adopted for the observations, and each of the ten points was observed for 30 minutes with a data recording interval of 5 seconds. The data were stored in Leica's .e00 raw data format and processed using Leica Geo Office software. The computed ellipsoidal heights are presented in Table 1.

Table 1: Data Collected in the Field.

Point	UTM Coordinates (Zone 40)		Ellipsoidal Ht (h) (m)
	Easting (m)	Northing (m)	
A	630550.696	2607269.562	8.261
B	630716.472	2607154.703	9.796
C	630739.528	2606961.338	11.953
D	630620.675	2606817.328	10.930
E	630448.193	2606792.496	10.136
F	630296.395	2606891.504	9.233
G	630238.291	2607106.729	6.981
H	630370.191	2607236.964	6.845
I	630407.318	2606959.961	8.788
J	630554.725	2606930.024	9.557

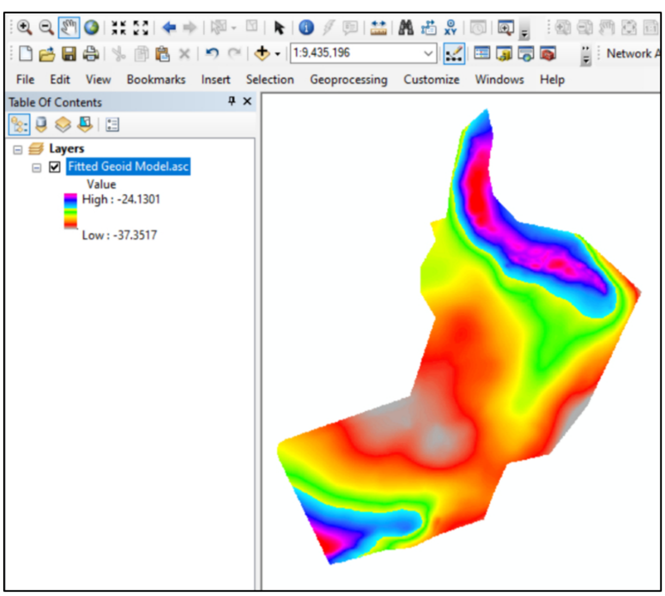
Source: Authors.

6. Oman Geoid.

Geoid is the term most appropriate to the irregular Earth surface. It does not have a mathematical representation, but it is the equipotential surface at mean sea level. Many researchers have attempted to represent its shape mathematically, but even to get somewhere near requires a series with 18^{th} degree terms [4].

The gravimetric Oman geoid model was developed by NSGIA in 2016 using the Residual Terrain Model (RTM) method and the GRAVSOFT software package. The model incorporated Shuttle Radar Topographic Mission (SRTM) digital elevation data with $3'' \times 3''$ and $30'' \times 30''$ resolution, which were transformed to the geoid level defined by the Earth Gravitation Model 2008 (EGM08) spherical harmonic coefficients. Additional datasets included historical Petroleum Development Oman (PDO) gravity data, new terrestrial gravity measurements collected at approximately 6,000 points using the Cintrex CG-5 gravimeter and referenced to the International Absolute Gravity Basestation Network (IAGBN), airborne gravity data, and bathymetric information from the General Bathymetric Chart of the Oceans (GEBCO) provided by the British Oceanographic Data Centre (BODC) at $30''$ (~1 km) resolution [12] [5]. A set of 35 first-order and 267 second-order GPS-on-benchmark points was supplied by the NSGIA. Furthermore, three new levelling lines with GPS observations on selected benchmarks were included for testing and fitting the geoid [11]. The final fitted Oman geoid model appears as shown in Fig. 6.

Figure 6: Oman Geoid Model produced by NSGIA.



Source: Authors.

7. Results And Conclusion.

For the corresponding Easting and Northing coordinates of the ten points, N values were extracted from the Oman Geoid Model using ArcGIS Desktop. These N values were then subtracted from the ellipsoidal heights to compute the orthometric heights. The actual MSL heights obtained from spirit levelling were compared with the orthometric heights derived from the geoid model. The absolute differences between the two height sets were calculated, as presented in Table 2.

Table 2: Data Showing N, Orthometric Heights and the Difference.

Point	UTM Coordinates (Zone 40)		Ellipsoidal Ht (h) (m)	Geoid Height (N) (m)	Orthometric Height (H) (m) H = h-N	MSL height from Spirit Leveling (m)	Difference in Orthometric and MSL (m)
	Easting (m)	Northing (m)					
A	630550.696	2607269.562	8.261	-27.46838	35.729	35.705	0.024
B	630716.472	2607154.703	9.796	-27.462585	37.259	37.219	0.04
C	630739.528	2606961.338	11.953	-27.454376	39.407	39.420	0.013
D	630620.675	2606817.328	10.930	-27.449051	38.379	38.305	0.074
E	630448.193	2606792.496	10.136	-27.446606	37.583	37.599	0.016
F	630296.395	2606891.504	9.233	-27.44828	36.681	36.681	0
G	630238.291	2607106.729	6.981	-27.455307	34.436	34.442	0.006
H	630370.191	2607236.964	6.845	-27.461849	34.307	34.297	0.01
I	630407.318	2606959.961	8.788	-27.449501	36.238	36.228	0.01
J	630554.725	2606930.024	9.557	-27.451939	37.009	37.022	0.013

Source: Authors.

The computed orthometric heights (H) closely match the spirit levelling MSL values across all points. Eight out of ten points show differences ≤ 2.4 cm, which is excellent for GNSS + geoid-based heighting for Engineering and topographic surveys. This reflects that the Oman Geoid Model is a reliable geoid model with good GNSS observation quality justifying proper application of H=h−N equation.

Point F (0.000 m) shows a perfect match between orthometric and MSL height. Points G, H, I, and C also show sub-centimetre to ~1 cm differences. These points demonstrate the practical equivalence of GNSS-derived heights to spirit levelling when conditions are favourable. Point D (0.074 m) stands out with the largest discrepancy (~7.4 cm). Possible reasons include local levelling errors, GNSS multipath or poor satellite geometry or Small-scale geoid undulations not fully captured.

Statistically and practically, the dataset shows excellent agreement between GNSS-derived orthometric heights and traditional spirit levelling. With an average difference of just about 2 cm, the results strongly support the reliability of GNSS + geoid-based height determination for local surveying applications. The single larger deviation appears to be an isolated case rather than a systematic issue, reinforcing confidence in the overall methodology.

Notable contributions of this work include the validation of GNSS/geoid-based height determination for engineering applications, assessment of the Oman Geoid Model, reduced dependence on time-consuming traditional spirit levelling, provision of a practical reference dataset for education and professional training, and support for local engineering and mapping projects.

Acknowledgements.

The author gratefully acknowledges the NSGIA, Sultanate of Oman, for providing seamless connectivity to Oman CORS network, which enabled reliable RTK data corrections throughout this work. The provision of the official Oman Geoid Model by NSGIA was also instrumental in accurately determining the geoid heights (N). The support and geospatial resources offered by NSGIA significantly contributed to the precision and success of this study.

References.

[1] G. Konecny, "Geoinformation: Remote Sensing, Photogrammetry and Geographic Information Systems", 2nd ed. Florida, USA: CRC Press., 2014.

[2] B. Hofmann and W.H. Moritz, "Physical Geodesy". 2nd ed. New York, USA: SpringerWien, 2006.

[3] A. Leick, "GPS: Satellite Surveying", 3rd ed. New Delhi, India: Wiley India Pvt. Ltd., 2004.

[4] J.R. Smith, "Introduction to Geodesy – the history and concepts of modern Geodesy", New York, USA: Willey - Interscience, 1997.

[5] USQ (2023) Datums and Coordinates [Online]. Available: https://usq.pressbooks.pub/gpsandgnss/chapter/in - the - beginning/.

[6] A. Leick, L. Rapoport and D. Tatarnikov, "GPS: Satellite Surveying", 4th ed. New Jersey, USA: John Wiley & Sons, Inc., 2015.

[7] B. Bhatta, "Global Navigation Satellite Systems", 2nd ed. Boca Raton, FL, USA: CRC Press, 2023.

[8] NSGIA (2025) OMANCORSNET. [Online]. Available: https://www.nsaomangeoportal.gov.om/en/oman-corsnet.

[9] NSGIA (2025) National Survey Authority – Site Overview. [Online]. Available: https://www.omancorsnet.gov.om/SBC/Account/Index?returnUrl=%2FSBC.

[10] Leica Geosystems (2025) Leica Viva GS14 Data sheet. [Online]. Available: https://downloads.leica-geosystems.com/files/archived-files/leica_viva_gnss_gs14_receiver_dat_us.pdf.

[11] NSA, "Geoid Model – Final Report: ONGM Project", Muscat, Oman, 2016

[12] GEBCO, "Gridded Bathymetry Data," General Bathymetric Chart of the Oceans, 2016. [Online]. Available: https://www.gebco.net/data-products/gridded-bathymetry-data. [Accessed 2016].

[13] USA, "Global Positioning System," United States Government, 2026. [Online]. Available: https://www.gps.gov/. [Accessed 2026].

[14] Russia, "About GLONASS," Russia, 2026. [Online]. Available: https://glonass-iac.ru/en/about_glonass/. [Accessed 2026].

[15] ESA, "Galileo," The European Space Agency, 2026. [Online]. Available: https://www.esa.int/Applications/Satellite_navigation/Galileo. [Accessed 2026].

[16] PRC, "?? | English," Public Republic of China, 2026. [Online]. Available: http://en.beidou.gov.cn/. [Accessed 2026].